Use of Round Mortise and Tenon Joints in the Construction of Furniture and Building Frames from Wood Waste and Small-Stem Woody Plantation Thinnings

By

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Introduction

Round mortise and tenon joints have been used in furniture construction for many years, but the true potential of these joints has seldom been recognized or utilized. Noteworthy exceptions to this statement are the "Shaker" ladder back chair and similar "mountain" chairs - the latter usually constructed of unseasoned woods - similar to that shown in Figure 1. In these chairs, round tenons, cut on the ends of the side stretchers, fit into matching round mortises bored into the front and back posts. These chairs derive their outstanding durability both from their design and their construction. Usually such chairs are constructed with three side stretchers. Owing to the relatively small size of the stretchers relative to that of the front and back posts, internal bending forces developed in the chair side frame during use are essentially evenly distributed to each of the six joints. Thus, the internal bending force acting on any joint is minimized so that no joint is overstressed. In addition, the joints are subjected almost exclusively to bending rather than tensile forces. Round mortise and tenon joints are able to develop their full bending strength even though loosely constructed, whereas the same joints will immediately pull apart if subjected to tensile forces. The net result is that by eliminating tensile forces through design, the need for close quality control in construction of the joints has also been eliminated.

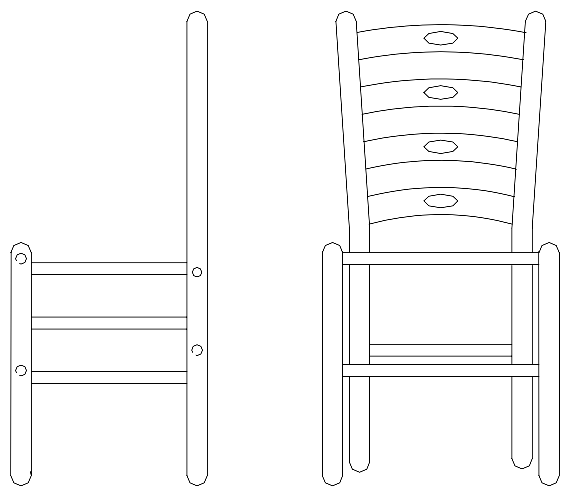

Figure 1. "Early" U.S. chairs constructed with round mortise and tenon joints.

The outstanding characteristics of round mortise and tenon construction has recently been demonstrated in a project devoted to the construction of durable school furniture constructed from wood waste including wood derived from plantation thinnings. In this project, chairs and desks, Figures 2 and 3, suitable for use in elementary school grades were constructed and subjected to performance tests used to evaluate furniture intended for adult use in university libraries. The experimental furniture performed as well as heavy duty library furniture.

Importantly, it was found that the tenons developed the full bending strength of the material of which they were constructed. Furthermore, the joints did not loosen nor show signs of fatigue during testing. To the contrary, during cyclic testing, the joints developed about 25 percent more strength than would be predicted on the basis of the static bending strength of the wood - which is in keeping with strengths predicted for short duration loading of wood. Presumably, building frames constructed with round mortise and tenon joints also would profit from this behavior in regions prone to earthquakes.

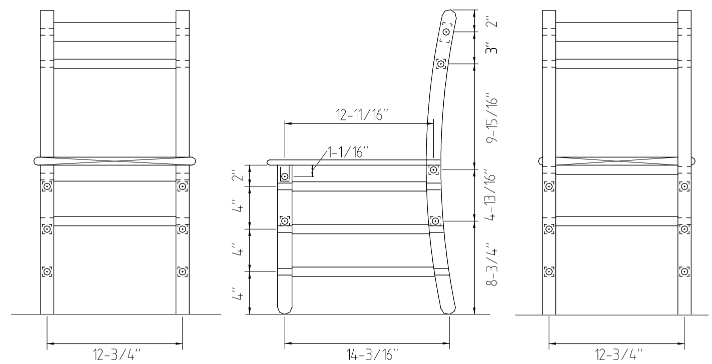

Figure 2. Solid wood chair constructed with round mortise and tenon joints.

Cutting Round Tenons

Traditionally, round tenons have been cut on a lathe, or, in the case of rustic furniture, with a draw knife. Various types of rotating cutter heads are also available today that are often used by home craftsmen. A particularly important finding for this project, however, was that deep hole saws may be used to cut high quality round tenons that are both uniformly round and uniform in diameter from one piece to the next. A simple horizontal drilling device, Figure 4, that simplifies and improves the quality of the cutting was developed in the laboratory. The principal components of the device are a one-fourth-horsepower electric motor, a wooden framework, and an inexpensive arbor, chuck, and hole saw. Total cost of the equipment should not exceed $50 US. Presumably, this simple piece of equipment could be constructed and used in many remote regions of the world - provided electricity is available. Where electricity is not available, the electric motor can be replaced with two bearings and a shaft so that it can be powered by other means such as a gasoline engine. The one drawback to the use of deep hole saws is that residual material not removed by the hole saw from the end of a stretcher subsequently must be removed in another operation, although this is not difficult.

Comparable simple equipment is presently lacking, but under development, for cutting tenons on the ends of large members to be used in conventional building construction. There are, however, several alternative ways in which these can be cut by hand. In the case of smaller support members such as wall studs, for example, the ends of the members can simply be “trued” to shape with a draw knife or machete. In the case of larger members, a groove can be cut to the desired diameter around the member with a handsaw, and the excess material split off the end of the member with ax or machete to form the tenon. This technique produces sharp shoulders

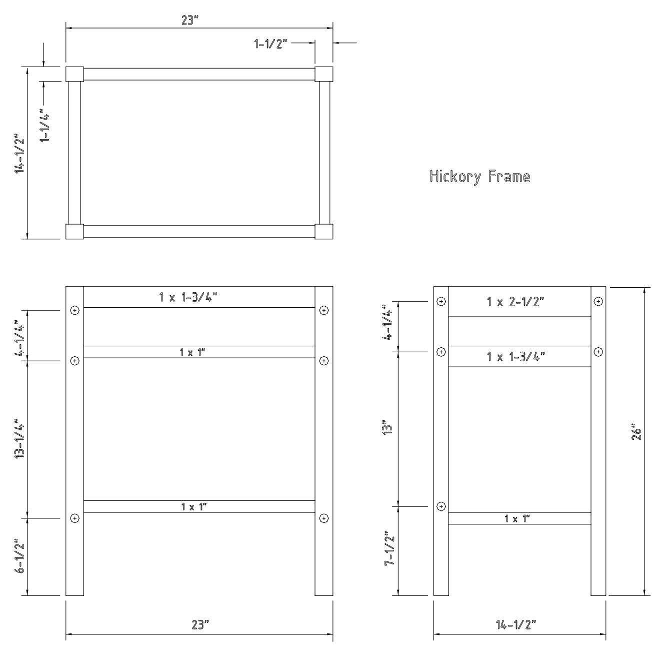

Figure 3. Solid wood desk frame constructed with round mortise and tenon joints.

on the members at the point of the cut, and hence is especially useful where shoulders are needed on the members. Round tenons can also be produced on the ends of member using only an ax or machete; these are satisfactory for many application where a shoulder is not needed.

Shrink and Swell Joint Construction

Shrink and swell joint construction refers to the process in which, tenons and mortises are machined while the materials of construction are maintained at an elevated moisture content or in the green condition. The tenon is cut slightly larger in diameter than the mortise. The part containing the mortise is then held at its current moisture content while the part containing the tenon is dried to a lower moisture content such as five percent. As the tenon dries, it shrinks to a size where its diameter is less than that of the mortise. The tenon is then inserted in the mortise and the two parts allowed to come to an equilibrium moisture content. During this process, the tenon swells while the mortise shrinks, and a “grip” fit is obtained.

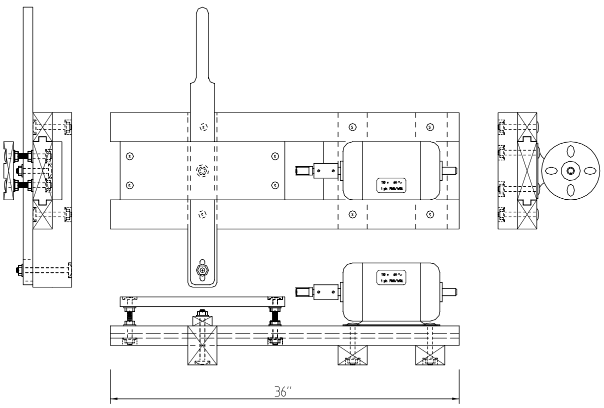

Figure 4. Simple equipment used to cut round tenons on the ends of members.

This process works well in those regions of the world where the wood naturally comes to a high equilibrium moisture content such as 16 percent. In drier regions of the world with lower equilibrium moisture contents such as 6 to 8 percent, only a shrink fit can be obtained since the dried tenons will swell little, but nonetheless, relatively high tensile joint strengths can still be realized. The designer’s problem is reduced to specifying these fits in such a way that they can be produced in practice. This entails only the specification of the maximum and minimum diameters of the tenon and the mortise at the time they are cut

Shrink fit joints are regularly used in the construction of “green wood” furniture (Alexander, 1994). Tension tests of shrink fit joints constructed by Alexander (2000) indicated that 3/4-inch diameter hickory tenons embedded 1 inch in red oak mortises, on average, developed an average withdrawal strength of 527 pounds with a standard deviation of 85 pounds in wood dried to 7 percent moisture content. This is certainly sufficient strength to hold a chair or other piece of furniture together provided it is designed in such a way that the joints are not subjected to high tensile loads. An extensive study currently underway at the Wood Research Laboratory soon will provide specific answers to optimum shrink and swell joint parameters and the withdrawal strengths that can be obtained from these joints.

An important point to consider when determining shrinkage fits is the stress developed in the walls of the mortise, which depends largely upon the shrinkage allowance. If the shrink fit is too tight, the ultimate strength of the wood may be exceeded, and the mortise will split. Likewise, the elastic limit of the tenon may be exceeded so that the tenon takes on a permanent set. On the other hand, if the shrink fit is too loose, a weak joint results.

Use of Hole Saws in Cutting Tenons

The hole saw is an invaluable tool for cutting tenons on the parts to be used in furniture or building frame construction in that these saws inherently cut tenons of uniform diameter without the need for close quality control by machine operators. Thus, once the appropriate mortise diameter has been determined, the construction of strong durable joints is reduced to the process of cutting the tenon with a hole saw and the mortise with a standard twist drill, drying the tenon until it fits into the mortise, and finally, inserting the tenon into the mortise and allowing it to swell while the mortise shrinks. Thus, with this construction, the need for close quality control is eliminated while an enduring construction is assured.

Green Bending of Wood

Many woods can be “free” bent sufficiently while green to form parts suitable for chair seats and back slats. In this process, the slats are simply bent to shape on a suitable jig and allowed to dry. In general, only simple equipment is required for the production of parts by this process.

“Creep bending” may be used, without steaming the wood, to form chair slats that include a relatively sharp radius. This “creep bending” process may be carried out with the pipe jig bending apparatus shown in, Figure 5. In practice parts are bent between two lengths of pipe by a third pipe located midway between the first two. A length of threaded rod located at each end of the center pipe with an attached nut is used to provide the force required to shape the laminations. Forces are applied perpendicular to the laminations by the walls of the two outer pipes only at the point of contact of the strips with the pipes. In service, one or more green strips of wood are inserted in the press and the nuts tightened on the center pipe until the strips are bent as much as possible without fracturing. The strips are moistened periodically, and the nuts again tightened at a later time - usually the next day. This process is repeated until the desired degree of curvature is obtained.

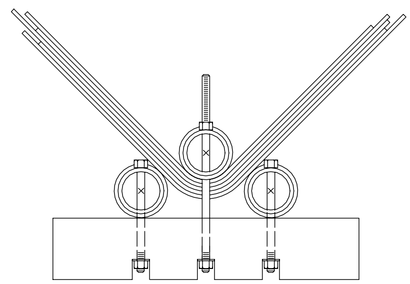

Figure 5. Simple pipe apparatus for “creep” bending green parts.

More complex curves may also be formed as shown in Figure 6. In this case, a bending jig is used to produce top rails for chairs in which the ends of the rail remain parallel to the original longitudinal axis of the rail. If desired, one end of the center load pipe may be pulled further down than the other end in order to provide a taper across the width of the back rails or back cross slats.

Back posts may also be bent to shape in the green condition. In this process, the back post, while green, is supported at each end and subjected to a load perpendicular to its longitudinal axis at mid span as shown in Figure 7. In practice, a back post is bent as much as possible without fracturing and allowed to creep under load. The clamping nut, shown in Figure 7, is periodically tightened and the back post allowed

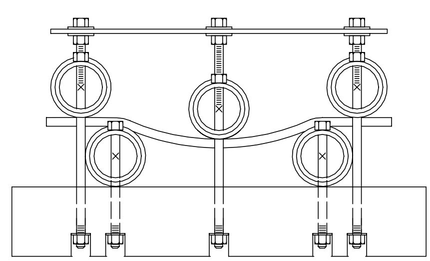

Figure 6. Apparatus for bending green chair top rails to shape.

to creep an additional amount. This process is repeated until the desired degree of curvature in the back post is obtained.

It should be noted that in this process, as the wood creeps, most of the creep occurs in areas of high stress. Thus, a round load head of small diameter will produce relatively sharp bends. Conversely, a large shaped load head with a gentle curvature may be used to produce sweeping curves.

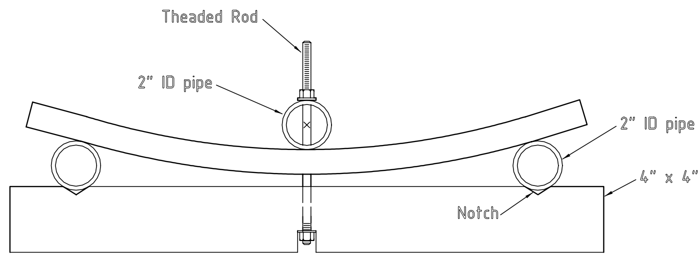

Figure 7. Green bending of back posts. Note that posts are bent in pairs.

Materials of Construction

Woody materials for construction of school furniture can be obtained from much of the material that is currently considered sawmill waste, from semi-processed material such as pallet deck boards, and from small woody stems obtained from plantation thinnings or from saplings grown specifically to provide the materials of construction. Many of the smaller furniture parts, in particular, can be cut from short and narrow boards salvaged from sawmill waste. Semi-processed materials are well-suited for the production of chair seat and back slats and for use in hybrid laminated construction. Small saplings can be incorporated directly into furniture construction, provide they have sound centers, but in many cases, such stems will need to be converted into squares or rounds or into processed parts before they can be used. In particular, small stems or saplings would be expected to be used for table and desk legs and front and back posts of chairs.

Green wood waste and stems are of particular value in that they can be bent to shape without the need for steam bending. Blanks for front and back posts for chairs, for example, can be bent to shape from squares or from small stems and subsequently bandsawn to final desired shapes. Similarly, seat and back slats may be bent from green material without the need for steaming.

Material for light frame building construction would come almost solely from small-stem woody plantation thinnings. Not all plantation thinnings are ideal for this type of construction - those with solid centers and superior juvenile wood properties are preferred. Use of this material in house frame construction, farm building construction, and light industrial building construction provides an enormous outlet for plantation thinnings and at the same time a solution to acute social problems, particularly in the area of affordable housing and other building constructions.

Solid Wood Furniture Construction

The configuration of a typical solid wood chair frame is shown in Figure 2. In these chairs, the stretchers and back rails are first ripped to 7/8-inch width and cut to length. Round tenons are then machined on the ends of each part with a 3/4-inch outside diameter hole saw. Excess material is removed from around the tenons as needed.

Front rails are constructed of 7/8-inch thick by 1-3/4-inch wide material. Round tenons are cut off-center on the ends of this member in order to allow the matching mortises in the front posts to be drilled slightly further down from the top of the posts. The top chair-back rail is also constructed of 7/8-inch thick by 1-3/4-inch wide material, but the tenons are centered on the ends of this member. Holes (mortises) to receive tenons for stretchers or rails are drilled completely through the posts. The drill used to bore the mortises in the construction of the furniture is chosen to provide a "shrink and swell" fit between hole and tenon. The back posts in the chairs with sloping back legs are either "creep bent" or bandsawn to shape

Assembly techniques vary, but, in general, the side frames are constructed first. Walls of the holes and tenons are first coated with adhesive. The tenons on the ends of the stretchers are then inserted in the holes and the assembly pulled together by means of bar clamps until the desired front-to-back side-frame dimensions are obtained. The side frame assemblies are then allowed to dry, and the holes for the front and back stretchers, etc., are then bored in the sides of the front and back posts. The walls of the holes are coated with adhesive, the ends of the tenons inserted, and the assembly pulled together as described above for the side frame assemblies.

The configuration of a sample solid wood desk frame is shown in Figure 3. Tenons are cut off-center on the ends of the top rails, Figure 3, in order to avoid interference with the tenons on the ends of the front and side rails. In some cases, this practice also allows the mortises for the tenons to be located a reasonable distance below the top of a post.

The side frames are constructed first. Walls of the holes are first coated with adhesive along with the tenons on the ends of the stretchers. The tenons are then inserted in the holes and the assembly pulled together by means of bar clamps until the desired front to back side-frame dimensions were obtained. Ordinarily, the end of the rail or stretcher will press firmly against the side of the post into which it was inserted. The walls of the holes for the front and back rails and stretchers are then coated with adhesive, the ends of the tenons inserted, and the assembly pulled together as described above for the side frame assemblies

Hybrid Furniture Constructions

Cross-lap laminated joint construction provides one of the simplest and most straightforward methods of constructing strong and dimensionally accurate side frames for both chairs and desks from either thick or thin wood slats. Cross-lap construction may be used to form both L-shaped corner joints and T-shaped rail to post joints. In form and function, these joints are equivalent to corresponding mortise and tenon or multiple mortise and tenon joints.

In constructing a side frames, the joint centers of the frame are first located on a flat plywood panel. Holes are then drilled through these points, and bolts are inserted through the holes. Corresponding holes are then drilled through the joint centers of the various laminations. The lap areas of the laminations are then coated with adhesive, and the pre-drilled laminations slipped over the ends of the bolts. Large washers are then slipped over the ends of the bolts, and the nuts are then threaded onto the ends of the bolts and tightened to apply pressure to the lap joint areas. Shorter lengths of material are glued in place in the slots between laminations in the front and back posts in order to produce solid legs. Thus, the front and back posts consist of three laminations each, whereas the side rail and side stretcher consist of only one lamination each. After the adhesive has dried, the frames are removed from the forms. The holes at the joint centers are then re-drilled to accommodate the round tenons of the front and back rails and stretchers, and the side frames joined together in essentially the same manner as with the solid wood furniture.

Cross-lap laminated construction is well-suited for those woods in which only short lengths of clear wood can be obtained or which have poor bending characteristics. This method of construction produces robust geometrically accurate frames with very simple equipment. Most importantly, limited quality control procedures are required to ensure the production of frames of uniform high quality.

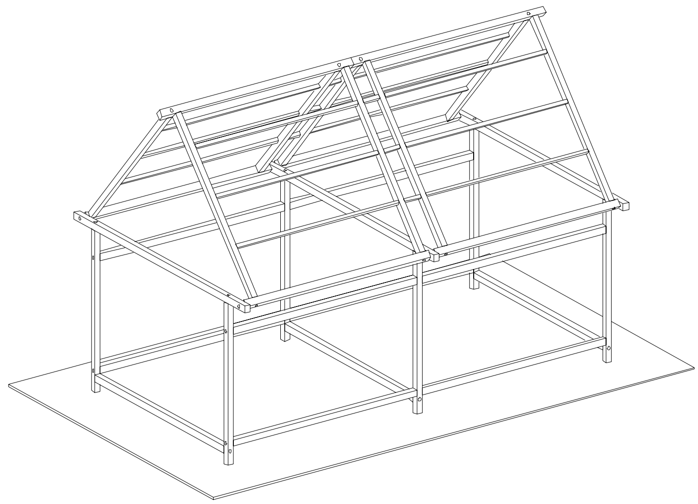

Figure 10. Diagram of practical building frame constructed with round mortise and tenon joints.

Building Frame Construction

Construction of a sample building frame that is intended to emphasize the use of the round mortise and tenon joints is shown in Figure 8. Note that all of the joints are loaded in shear or bending, or in compression, but none of the joints are loaded in tension. The ends of the vertical posts may be buried in the ground - as would be the case with pole barn construction - or, they may be set on a conventional foundation. Framing for doors and windows is not shown but may easily be added. Shrink and swell joint construction is not used in this building frame construction, but a close fit between tenon and mortise is desirable.

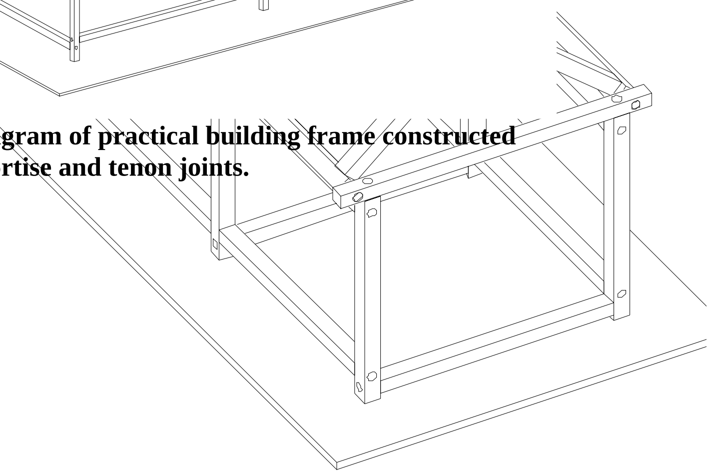

Figure 8. Building frame constructed with round mortise and tenon construction from “squared” woody stem plantation thinnings.

A practical construction that illustrates the use of modular concepts is shown in Figure 9. The ceiling beams may be extended to provide as large a roof overhang as is desired. The roof purlins frame into the sides of the roof rafters to provide a planar roof surface and to add rigidity to the total construction in the lengthwise direction.

Round mortise and tenon joints may also be incorporated into conventional log frame constructions to provide simpler more robust constructions. Figure 10, for example, shows an end frame of the type used in early log frame post and beam constructions. In this construction, roof loads are transferred primarily to the ceiling beam and from there to the posts at either end of the beam.

Discussion and Conclusions

Although round mortise and tenon construction has been used in furniture for hundreds of years, its value in the solution of human needs problems has never been fully appreciated. Round mortise and tenon joints together with shrink and swell construction allow low cost, durable furniture to be constructed from essentially waste woody materials using only the simplest manufacturing techniques. Thus, attractive affordable school and domestic furniture of all kinds, built to "last a lifetime - and more," can be constructed in even the most remote regions of the world from locally available materials using only low technology processes. Only a small investment is required to empower local communities to develop their own production facilities. At the same time, the same processes are readily adaptable to the production of durable maintenance free furniture in even the most developed countries..

The use of round mortise and tenon joinery in conventional building frame construction provides a means of utilizing extensive wood plantation thinnings in the solution of housing shortages as well as a means of producing low cost farm and light industrial buildings. Significant research remains to be carried out to determine the strength of the joints, optimum frame constructions, and the types of preservative treatments needed to ensure the durability of the constructions. Likewise, research is also needed to determine those wood species best suited for use in this type of construction. To date, research on building frame constructions has been carried out with large models. As soon as concurrent joint strength and durability tests are completed, full scale building construction and testing will be undertaken. Once the necessary research is completed, however, it is anticipated that standardized modular designs can be created that require a minimum number of part sizes and limited quality control practices in order to produce simple, easy to build, robust, durable frame constructions.

In conclusion, therefore, it appears that round mortise and tenon joints along with the fortuitous development of the hole saws needed to make them provides a rare opportunity for improving the quality of life of many peoples of the earth while simultaneously using what would otherwise be considered wood waste. It is a particularly unique opportunity in that it provides environmentally friendly solutions to chronic social problems. Results of this program will not be translated into practice, however, unless political support is developed for the program, ways are found to transmit the information to those who most need it, and local production facilities are developed to implement the findings.

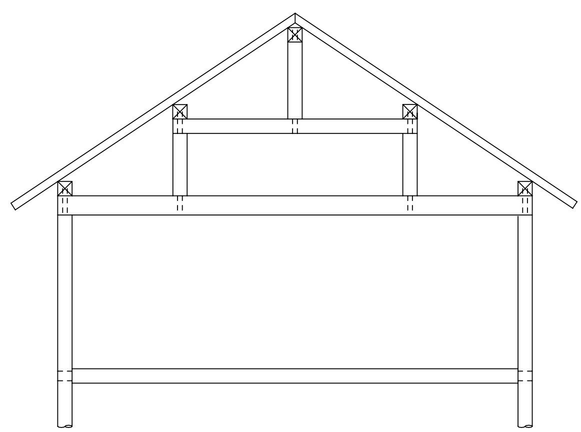

Figure 11. Diagram of early log frame post and beamconstruction.

This program began with a problem and developed a solution. It is still open to whatever local factors may be relevant. The simplicity and fundamental nature of the proposed solutions lead naturally to local and regional experimentation that is expected to develop naturally and to future collaboration among public agencies, training institutions, and governmental bodies. In short, it leads to local empowerment through the broad-based participation of local populations and relevant regional agencies.

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